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# Application of European design principles to cross laminated timber

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ABSTRACT

The design of cross laminated timber (CLT) structures is not included in the current version of European structural timber design standards of EN 1995 (Eurocode 5, EC 5). Due to the increasing importance of CLT, in different applications such as complete wall or floor elements as well as girders, it is one of the main goals of the currently ongoing revision of EC 5 to provide design principles for CLT structures. In the present paper some general aspects, relevant for the implementation of CLT in European standards in order to be consistent with the general philosophy of the Eurocodes are summarized and discussed. The differences between standard test specimens and structural components as well as the uncertainties related to the production procedure of CLT and the non-standardized test procedure are discussed. An investigation of 12 different test series from five different producers clearly indicates a large variation between different production series. Based on the investigation from the test series a reliability analysis is performed. The results indicate that the same partial safety factor as recommended for glued laminated timber (GLT) is appropriate in order to achieve an acceptable reliability. However, the analysis also indicates the potential for a smaller partial safety factor in the future, in case that the production of CLT is standardized and appropriate standardized test methods for the individual material properties exist.

## 1. Introduction

A large proportion of the societal wealth is invested in the continuous development and maintenance of the built infrastructure. It is therefore essential that decisions in this regard are made on a rational basis; i.e. to balance expected consequences and the investments into more safety. Structural design codes are therefore calibrated on the basis of associated risks or, simplified, on the basis of associated failure probabilities. Reliability based code calibration is already implemented in several modern design codes, such as OHBDC [39], NBCC [38], or EN 1990 [17]. For background information about reliability based code calibration it is refereed to e.g. Rosenblueth and Esteva [41], Ravindra and Galambos [40], Ellingwood et al. [14].

The current version of European structural timber design standards of EN 1995 (Eurocode 5, EC 5) provides no design principles for cross laminated timber (CLT) structures. This large-dimensional plate-like, stand-alone structural timber product can be used as complete wall or floor element as well as girder. Due to the growing importance of CLT in the construction sector, it is one of the major goals of the European Cooperation in Science and Technology, COST Action FP1402, to provide design principles for CLT structures in the new version of EC 5.

The timber construction product CLT is, compared to other building materials, relatively new on the market; the first CLT elements where produced in Central Europe 25 years ago. Although meanwhile worldwide CLT productions exist, Central Europe, in particular the alpine area, still remains as hot spot with a share in worldwide production volume of 90% (800,000 $m^3$), produced in nine large CLT productions (more than 20,000 $m^3$ per year; three of them produce even more than 100,000 $m^3$ per year) and 23 small and medium sized productions see [43]. The majority of CLT from Europe has many common parameters, e.g. the most common timber species used is Norway spruce (Picea abies), the base material (lamination) is mainly strength class C24 or T14 according to EN 338 [20] and the layers are usually bonded at their side-faces but not or only unintendedly at their narrow faces (edges). There is also a strong tendency standardizing the CLT layups and the layer thicknesses to 20, 30 and 40 mm.

In this paper, relevant aspects for the implementation of CLT in European standards are summarized and discussed. Hereby it is particularly focused on issues and challenges that are associated to the formulation of design equations that are consistent with the general philosophy of the European Design Standards as prescribed in EN 1990 [17]. In the first part the differences between standard test specimens

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and structural components are discussed. Afterwards the representation of material properties for structural design and code calibration are introduced. In Section 4 the variability of the material properties of CLT is investigated and discussed. The focus is on the uncertainties related to the production procedure of CLT and the non-standardized test procedure. Thereafter, the variability of selected material properties and strength related issues are discussed based on the results from other investigations. Using thereby identified variabilities a simplified reliability based code calibration is performed.

## 2. CLT – standard test specimen vs. structural components

When modelling timber material properties in a structure, i.e. at any generic point, in time and in space, several issues related to timber grading, size effects and static fatigue effects have to be taken into account, see also Köhler [32]. For engineered wood products, such as CLT, the situation is even more complex as the joint behavior of the assembled timber boards, the finger joint connections and the bond lines have to be represented. Furthermore, the production process of engineered wood products might affect the variability and uncertainty of the properties of the product.

In Fig. 1 the various aspects that influence the load bearing capacity of CLT at a generic point in the structure are illustrated. The base material for the production of CLT is graded structural timber. Graded structural timber is available in form of strength classes, i.e. classes of structural timber with specified target reference properties as timber density, modulus of elasticity (MOE) and bending or tension strength (MOR). The targets for the reference properties are expressed as fractile or mean values from the corresponding anticipated probability distribution functions; 5% fractile for the density and the MOR and mean values for the MOE. All other material properties of the graded structural timber are estimated based on the classification made based on the reference properties. It has to be considered that the reference properties representing the properties of the entire strength grade, but not necessarily the properties of an individual batch (see also Fig. 2). Obviously the variability between the sawn timber batches is related to the quality of the grading device that has been used. Different base material strength classes can be used for the production of CLT and different production techniques exist to produce a classified and specified CLT product, see e.g. [42,26,27,9].

Classified engineered wood products have assigned values for the strength and stiffness properties associated to different possible failure modes. These failure modes relate to standardized test set ups that are specified in order to imitate the loading and failure modes in real structures as close as possible. Test data from these standardized tests are taken to verify the strength and stiffness properties of the engineered wood product and to quantify the variability, e.g. the coefficient of variation (COV), of the measured properties. For CLT a test standard is missing. Some test setups and recommendations can be found in EN 16351 [16] and EAD [22], former CUAP [12]. However, in the recent experimental investigations often, a relatively large amount of the tested specimens show failure modes different to the target ones (see Section 4.2.2).

Together with the analysis of model calculations for the corresponding failure modes the entire production and classification process is calibrated and validated. However, the production and classification process is not perfect and under full control, thus, beyond the uncertainty that is associated to the variability of measured test data the uncertainty due to the imperfect production and classification process has to be considered.

Furthermore, it has to be considered that the identified material properties are related to standardized tests and not to the strength and stiffness related properties in a generic point in the structure. Scale, size and system effects, static fatigue effects and moisture effects as well as a possible combination of different loading modes also affect the relevant property (strength and stiffness) and have to be considered.

Due to similarities between CLT and glued laminated timber (GLT) many of the above mentioned issues might be adaptable. However, for some issues such as the production process or the test procedure significant differences exist and have to be considered. Furthermore, different areas of applications as well as additional failure modes have to be considered. At this point it has to be mentioned that some of the above mentioned issues are not yet solved for GLT; i.e. the assumptions are often based on engineering judgment. However, due to relatively long experience with GLT in structural applications the assumptions made seem to lead in reliable solutions even though they might not be fully optimized yet.

CLT is currently available with numerous different layups, including different number and thicknesses of the individual layers. The different setups might lead to different strength properties, but the differences might be rather small for CLT having homogeneous material, symmetric setups and only rational differences in the layer thicknesses; thus for the majority of the CLT plates. Accordingly, in most of the existing models the strength and stiffness properties of CLT are directly related to the strength and stiffness properties of the lamella.

## 3. Representation of material properties for structural design and code calibration

The objective of structural design is to choose structural dimensions

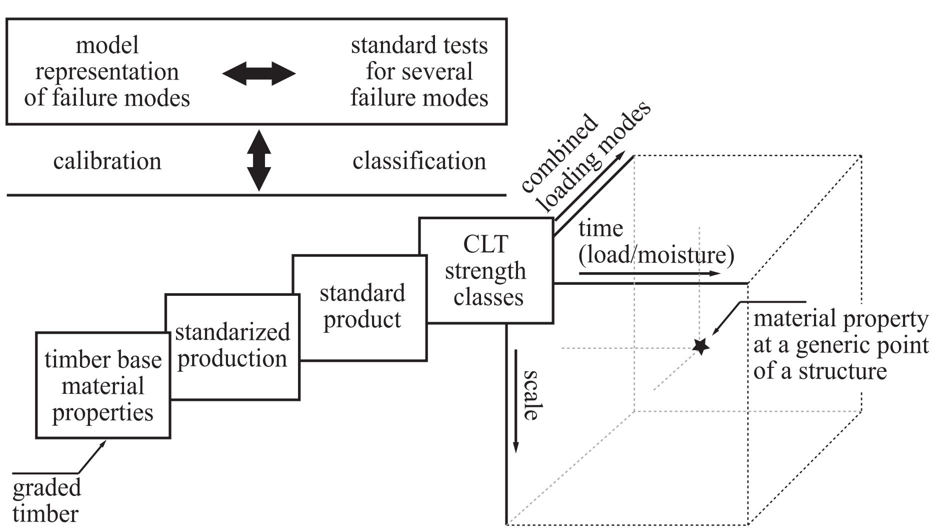


**Fig. 1.** Strength and stiffness related properties are relevant to represent in structural design assessment. However, this includes the consideration of various aspects.